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The R&D Factor in Corporate Planning

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This interview with Michael E. Brose, President of Technology Consulting Group Inc., Boston, explores current trends in R&D planning and looks at R&D's role in the future of the nation's industries. An MIT and Sloan School graduate, Mr. Brose has over twenty-five years' combined industrial and consulting experience in strategic business planning and technology assessment.

SOM: I'd like to start by asking you where R&D fits in the corporate plan today. What are the typical perceptions?

MB: Basically, corporate planning rarely includes R&D considerations. Most Fortune 500 companies ask that R&D plans be submitted separately from the business plan. The intention behind this is not only to give the corporation some awareness of technology issues, but to avoid "complicating" the business plan with the technology plan. R&D planning is viewed as an independent exercise carried out by the research and technical side of the business, while the actual business plan is executed by everyone else — the financial, marketing, planning, and, to some extent, product engineering departments.

SOM: Should corporate planners continue to treat R&D as separate but not equal?

MB: It can be separate, but it needs to be equal. It should be integrated into the overall process, and that means having the R&D people become active participants and partners in planning. R&D people need a better awareness of the current issues confronting the oper-

ating business; likewise, the operating people can benefit from greater exposure to the potential technologies available in research and development. I'd like to see more firms prepare an *integrated business and technology plan* that incorporates the R&D plan. And the R&D plan should address the business plan's strategic issues.

SOM: Are you advocating an elevation in status for the technicians and engineers involved in the R&D effort?

MB: Absolutely! Many companies still treat R&D staff members as second class corporate citizens of questionable ability to address business issues. Unfortunately, that runs counter to most of our experience at TCG. We have repeatedly found that R&D people are very broad-range thinkers with sound perceptions about business, the economy, and trade. They are well-informed and very insightful, and have a lot to contribute to business planning. In fact, technology people understand business issues far better than business people understand technology issues. The notion that technology and R&D staff members shouldn't participate in business planning because they lack business acumen simply doesn't wash.

Instead of isolating technical managers from both the market and technological strategic planning, management should be involving them more fully. Unless the business strategy is developed with the participation of those who really understand the fundamentals of the business, it is far less likely to succeed.

SOM: What are the advantages of an integrated business/technology plan developed with the full participation of R&D?

MB: First, you need to integrate technology into business planning as a competitive weapon either to gain or maintain market share against your competitors. If you don't do that, the consequences can prove disastrous. U.S. tire makers sat on their hands while radial tire technology took over the U.S. market and foreign competitors established a major beachhead. Now Michelin has sever-

al plants in the U.S., and has captured a large market share. The success of foreign corporations in the U.S. market has shown that you can develop products that customers will want and buy, if you more closely couple R&D manufacturing technology with business know-how.

A second major advantage of integrating the technical and business plans is greater visibility for manufacturing and process technology issues. For example, quality improvement can be viewed not just as a manufacturing issue, but as a competitive advantage that helps maintain market share. American management needs to change its traditional view that regards the costs of quality control and process improvement as frills. I think American industry is finally beginning to recognize that investments in process and factory automation will pay off in better quality and higher margins.

SOM: Does the need to integrate technology into business planning apply to mature industries as well as to high technology industries?

MB: Mature industries face the toughest challenge of all. Because mature industries have product life cycles ranging from ten to twenty years, they can get hurt very badly if they do not keep up with changes in technology. We talked a minute ago about the tire industry, clearly a mature industry which suffered by choosing to protect its existing assets instead of investing in new technologies. Steel is another capital-intensive industry that failed to invest in appropriate technology changes; as a result, it has lost much of the market in this country.

On the other hand, in the fast-paced electronics industry, the introduction of new technologies is a way of life. Moreover, the industry's production facilities are less capital-intensive and much more labor-intensive. This enables the industry to keep pace with technology changes while investing modestly. But the capital-intensive, mature industries have a lot more at stake because catching up can require five to ten years and staggering investments.

SOM: Is the direction of R&D determined by the overall strategic plan, and what percentage of the budget should be allocated to R&D?

MB: Most of the R&D budget should be allocated in accord with the strategic plan, but keep in mind that we advocate having R&D involved in shaping that plan. Of course, we're talking now about the R&D budget, not just about the product development budget. Let's be clear about this point. When you look at an annual report, and a company tells you that it spends 2.7% of its sales dollars on R&D, that includes all current product engineering as well. Typically, only about 10-20% of the total R&D budget is actually devoted to R&D for truly new products.

As for the percentage of sales that should be devoted to R&D, the answer depends on the particular industry and each company's strategy within its industry. But, as a general answer, we believe that U.S. industry, on average spends about 20-35% less on R&D than it should. For the U.S. as a whole, total R&D spending as a percentage of GNP fell from 3% in the early 1960s to a dan-

gerously low 2.3% in 1980. Fortunately, that trend has reversed somewhat; in 1983 the figure had risen to about 2.5%. Basically, the decline in R&D spending resulted from an overreaction in the middle to late 1960s, as the aerospace and NASA programs began to wind down. Top management began to question the usefulness of R&D and to ask, "Are we getting anything for our R&D?" And, if R&D couldn't yield demonstrable short-term results, then managers began to cut funding and, subsequently, to close down their corporate R&D laboratories.

SOM: Should the guideline of increasing R&D spending apply to older, mature industries as well as to so-called "high-tech" industries?

MB: Yes, because R&D and advanced technology are equally important to both types of industries. But, I'd like to make a key distinction between "high tech" and "low tech" and between mature versus growth industries. Thanks to Wall Street and the investment community, there is a lot of confusion and misuse of those terms. Wall Street would have you believe that a mature industry, like steel, is a low-tech industry. Nothing could be further from the truth because the technology of steel-making is exceedingly complex and involves highly specialized knowledge of metallurgy, metal-forming processes, controls and instrumentation, and a wide range of other technologies.

At TCG we recognize that every industry has a technology component. After all, what is technology? We define it as the mix of skills needed to create and produce a product, or to provide a service, that meets a customer/market need. Viewed this way, it is easy to see the importance of R&D to every company.

SOM: Do you think, Mr. Brose, that survival in the world market will require U.S. firms to adopt an approach similar to the Japanese emphasis on R&D and technology development?

MB: We're probably going to have to change our structure in some way to enable U.S. industry to become more competitive in the world market, but whether that means changing it to resemble the Japanese model is less clear. There are certain things that the Japanese can do, because of the tremendous concentration of their industries, which are unacceptable to U.S. antitrust laws and to our notions of fair competition. However, that doesn't mean that U.S. firms can't cooperate more often in joint research efforts. An interesting example of this sort of cooperative venture is the Semiconductor Research Corporation in Research Triangle Park, North Carolina. The SRC is funded by all the major U.S. semiconductor makers, as well as leading computer manufacturers, who sit on the Board of Directors and channel funds to leading universities for pure research related to semiconductor manufacture. All investors share equally in the results of research, which could not have been conducted without their cooperation. When investing members subsequently develop the results of this joint research, American free competition re-enters the picture. This "industry concentration American style" is worthy of emulation in other U.S. industrial sectors.

Another pertinent issue in the U.S. is the extent to which government, business, and labor can become true partners. I think we can see that management and labor in the United States are beginning to grow closer. That is certainly a positive sign. Less clear to me is how much government is willing to participate in this partnership. American industry and Washington have traditionally been at odds. While I don't see any major changes yet, there are signs that U.S. managers are beginning to recognize the need to do something different if we are to compete with foreign companies that have strong government support. Somehow, government must be the third party at the table if we're really going to compete effectively in international markets.

SOM: What specific actions should the U.S. government take?

MB: Government should get more involved with industry and labor to understand the key issues, and then set about doing what government can do best, which is to make policies that will enable American industry to compete fairly in international competition and commerce. What American manufacturers need most is a sound U.S. trade strategy that recognizes the need to maintain a strong industrial manufacturing base in this country to provide jobs for our working men and women, as well as to maintain our national defense capabilities.

Both the Congress and the Administration should be seeking to establish trade import and export policies based on specific product classes, not just total dollar amounts. By this I mean that if a country, such as Japan, takes 10% of the U.S. car market, then the U.S. should have access to 10% of the Japanese car market. We need to remember that virtually every other country in the world is already strongly protectionist. Only the U.S. continues to allow itself to be a sink for imports from other countries, with no reciprocal agreements or conditions for U.S. exports.

Certainly, the Congress must address the deficit issue so that we can establish some sanity in the balance between the U.S. dollar and European and Japanese currencies. But we also need tax legislation that provides true incentives for corporations to invest, and to make sure that we don't get into boondoggles like we did with the R&D tax credits. Incentives ought to be given for true capital investment. We can't give tax credits or establish import quotas for the steel industry and then let U.S. Steel buy Marathon Oil instead of investing to modernize its steelmaking facilities. If government creates a better business environment in which U.S. industry can compete, then industry should do something in return. I am very strongly in favor of tying the performance of U.S. industry to the benefits that it receives from government intervention.

SOM: Finally, what do you see as the future role of R&D in U.S. industry? Is it going to be the guiding light?

MB: It really has to be. If it's not, we're going to be in deep trouble. Clearly, the tide of innovation is shifting away from the U.S., which has always been considered the world's leading innovator. Japan, Germany, and Rus-

sia now vie for that honor. Without the flow of new products resulting from research and development, American industry simply can't maintain its leadership. The question is how long can the U.S. continue to live on existing technologies, the way we've been doing, instead of investing in new technologies for the future? The MBAs have told us that it doesn't pay to be innovative in the short term. Currently, that view is disguised under the euphemism that a company can be a "fast follower" rather than a leader in new technology. Meanwhile, both the Japanese and the Europeans have seen that the U.S. market is "easy pickings" because American companies are so preoccupied with short-term results. Eventually, we'll have to shift to more long-term thinking and recognize that business has a future beyond quarter-to-quarter profits.

We in the U.S. desperately need to rekindle the flame of innovation that burned so brightly in earlier years. We need R&D because we need the creative new ideas that can help a company build its future business. We must invest in R&D to assure that future.

Twelve Receive M.B.A Degrees in Management Information Systems

In May 1984 the School of Management awarded twelve M.B.A. degrees to students who fulfilled the requirements for SOM's new M.B.A. concentration in Management Information Systems (MIS). Similar in structure to SOM's general M.B.A. concentration, the MIS submajor includes additional courses that prepare students for careers in management systems analysis and design. The MIS concentration emphasizes such skills as statistics, management science, and management systems problem solving. The twelve MIS graduates are currently employed at IBM, Electronic Data Systems, Data General, Hewlett-Packard, Texas Instruments, and General Electric. For further information about the School of Management's MIS concentration, please contact:

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Productivity and Its Conceptual Abuse

Louis Wigdor

Editor

Massachusetts Business & Economic Report

In their proposals to restore the nation to economic pre-eminence, American political leaders have frequently espoused the goal of greater productivity. They are joined by a chorus of economists, business leaders, and business writers, the latter whose devotion to the cause is reflected in such book titles as *The Productivity Prescription*, *The Productivity Dilemma*, and *Productivity by Objectives*.

Although talk of productivity is widespread, it is an elusive term that means different things to different people. As the Committee for Economic Development notes: "The main difficulty in trying to measure productivity growth or decline is the inherent ambiguity of the concepts involved. There is simply no single definition of the term 'productivity.' Consequently, there is no one correct way to measure its growth."¹

Discrepancies abound but students of productivity do agree that all productivity measurements contain a common thread. This is that productivity is a *ratio* relating output (usually goods or services) to one or more related inputs (labor, capital, energy, etc.). Of course, productivity measures must be sufficiently varied to accommodate such domains of activity as the national economy, major economic sectors, individual industries, and firms.

The most frequently cited productivity measures for the national economy and its major sectors are the US Bureau of Labor Statistics' (BLS) labor productivity indexes. These indexes measure productivity output as the gross national product of either the entire national economy or of its individual industrial sectors. Productivity input measures are based largely on monthly payroll records, thus emphasizing the concept of pay per hours worked over that of total hours worked. The BLS has also developed similar indexes for about ninety individual industries such as steel, motor vehicles, and coal.

Because the BLS inputs are based solely on labor, BLS productivity indexes are relatively easy to compile but are analytically simplistic. A more comprehensive picture of productivity emerges from indexes that employ more than one type of input. These indexes, known as "total-factor productivity indexes," combine a labor-input series with a capital-input series, including such factors as land, equipment, buildings, and inventories. Three private researchers who publish influential total-factor productivity indexes are John W. Kendrick, Edward F. Denison, and Dale Jorgenson.²

Writing for the American Productivity Center, John Kendrick strongly recommends total-factor indexes. He notes that "... in contrast to partial productivity measures, total productivity reveals advances in overall pro-

ductive efficiency — the same output with lowered total input."³ He adds that "only by relating output to both labor and capital can it be determined whether there has been a net saving of factor inputs per unit of output, and, if so, how much of a saving."⁴

One might expect politicians to speak of productivity with less rigor than economists, but would hope for greater precision from members of the business community. The business community has a long way to go, according to recent research by Professor Jerome Kraus of the City University of New York. His recent survey of 125 large US corporations reveals mind-boggling diversity in their approaches to productivity measurement.⁵ Most startling is that nearly half the companies surveyed have no firm commitment to productivity measurement that relates output to inputs. Indeed, 58 of the 120 (48.3%) firms do not use such ratios as "most important productivity measures." Moreover, 46 (38.3%) fail to use input-output or output-input ratios at all. Kraus discovered that some chemicals firms measure productivity as "volume" and "sales," while some metal products firms regard productivity as "monthly changes in working capital." The list of measures that fail to relate inputs to outputs goes on and on.

Although recommended by the American Productivity Center, total-factor productivity measures are either used or planned by only 18 of the 125 firms. Among the 17 standard industrial categories surveyed by Kraus, communications firms employed the most sophisticated productivity measures. The telephone industry most consistently employed total-factor measures, including the following index:

$$\text{Total-factor productivity} = \frac{\text{Output}}{\text{Inputs}}$$

[operating revenues minus nonincome taxes] [gross capital, labor, service]

Although some firms have developed sophisticated indexes that could provide models for other firms and industries, Kraus concludes that productivity measurement is "still in its infancy." Thus, the public would do well to scrutinize statements by politicians and business representatives about productivity. Considering the term's rampant abuse, blanket acceptance could prove highly unproductive.

Notes

¹Policy Committee of the Committee for Economic Development, "Productivity Policy: Key to the Nation's Economic Future, 1983, New York, Committee for Economic Development, p. 10.

²Jerome A. Mark, "Productivity Measurement, in Jerome W. Rosow, ed., *Productivity Prospects for Growth*, 1981, New York, Van Nostrand Reinhold, pp. 64-65.

³John W. Kendrick in collaboration with the American Productivity Center, *Improving Company Productivity*, 1984, Baltimore, The Johns Hopkins University Press, p. 11.

⁴*ibid.*

⁵All findings from the Kraus study are available in Jerome Kraus, *How US Firms Measure Productivity*, 1984, New York, National Association of Accountants.

The July 1984 Massachusetts Economic Policy Analysis (MEPA) Economic Forecast

Roy Williams and Margaret Larson*

Recent strong growth in the national economy is not broadly reflected in current data for Massachusetts. Except for the state's incredibly low reported unemployment rate for the last three months, there is little evidence that the recovery here is still vigorous. Employment by industry grew substantially less in the second quarter of 1984 than we had forecasted it would in April. In most sectors, Massachusetts employment as a share of U.S. employment dropped appreciably over the last four quarters, and the MEPA model again forecasts continued declines in share for almost every industry. Since April, our forecast has changed because of revisions in personal income data back to 1980, a new national forecast from Data Resources, Inc. (DRI), and four months of current state employment and unemployment data. Revision of historical wage and salary data, now more consistent with previously rebenchmarked employment data, particularly in the trade and construction sectors, accounts for most of the reductions in forecast growth compared with the MEPA April forecast.

While employment is now lower than we thought it would be, the unemployment rate has dropped astoundingly to the four percent level. We emphasize again that this unemployment rate is based on a survey of only 1,500 households in Massachusetts. According to these calculations, the total number of Massachusetts residents who say that they are looking for work decreased in the second quarter of 1984 by 41,000 while the total number of residents who were working increased by over 84,000. These figures present an enormous discrepancy with the CES survey of establishments, which showed only 2,500 new jobs (seasonally adjusted) created in Massachusetts in the second quarter. The discrepancy cannot be blamed entirely on the unemployment rate, which has at least been very consistent for three months. We believe that the CES survey count of jobs is also too low, especially in Trade, Services and in some manufacturing sectors. Recent rebenchmarking of employment data, incorporated into our April forecast, did bring up employment figures for the past year, especially in Trade. These revisions of last year's employment data used March of 1983 as the benchmark month, so they do not yet show the full effect of the repeal of the Massachusetts Blue Laws. We expect that reported data for employment in Trade, Services and many manufacturing

sectors for 1983 and 1984 will be revised upward again next year when complete payroll data for March of 1984 are used to rebenchmark the current estimates based on the CES survey of a sample of establishments.

Differences in definition may also explain part of the discrepancy. The count of wage and salary jobs excludes the self-employed as well as unpaid workers in family businesses. In recent years the self-employed have been growing rapidly, and the current recovery can be expected to strengthen that trend. In a strong recovery, we would also expect an underestimate of the number of workers in new businesses, since statistical imputations must be used to supplement the sample of existing firms.

In presenting their July forecast for the nation, DRI emphasized the change in its forecast for inflation. DRI previously expected that interest rates would rise sooner and higher than they have, and that food and energy prices would remain very stable. Nationally, wage restraint is also expected to continue for the near future in spite of a probable auto strike. If the labor market in Massachusetts is really as tight as our unemployment rate suggests, we should expect to see some upward pressure on local wages. Overall price inflation in Massachusetts is expected to be very close to the national average.

The Massachusetts economy has, by just about every measure, improved over the past year and a half, but by amounts generally less than we had predicted (except in the case of the unemployment rate), and by rates less rapid than those corresponding measures of the U.S. economy. We forecast continued slow overall growth, continued drops in share of the U.S. employment, and unemployment rates continuing well below those of the nation. We hope that when the data inconsistencies currently clouding our crystal ball are cleared up, we will see a more uniformly optimistic picture of the state's economic future.

*Associate Director and Research Assistant, respectively, of the MEPA Project, Economics Department, University of Massachusetts, Amherst, MA 01003. (Tel. 413-545-0915). Technical assistance provided by John Lanzillo, MEPA staff. Support from the Department of Public Welfare, the Division of Employment Security, the Boston Redevelopment Authority, and Massport. National inputs from CONTROL062684 and HARDLANDING062684 from Data Resources, Inc.

July Control Forecast

Summary Report

Massachusetts Economy Policy Analysis Model

(Units as Indicated)

	1984	1985	1986	1984:2	1984:3	1984:4	1985:1	1985:2
Employment—Total Nonag.*	2729	2768	2790	2718	2736	2747	2759	2767
% Change	2.2	1.4	.8	.4	2.6	1.6	1.8	1.1
Manufacturing*	641	643	637	640	642	644	646	645
% Change	2.7	.3	-1.0	-.2	1.5	1.1	1.3	-.4
Non-Manufacturing*	2088	2125	2153	2079	2094	2103	2113	2122
% Change	2.0	1.8	1.3	.6	3.0	1.8	2.0	1.6
Unemployment Rate	4.8	4.6	4.9	4.4	4.5	4.5	4.4	4.5
Employment Rate Index**	106.4	107.6	108.1	106.0	106.6	107.0	107.4	107.6
% Change	1.7	1.1	.5	-.2	2.4	1.3	1.4	.7
Relative to U.S. Index**	103.9	103.4	102.8	103.6	103.7	103.6	103.5	103.4
Rate of Wage Change	4.0	3.9	5.6	4.5	3.5	3.5	3.8	3.4
Wage Index Rel. to U.S.**	96.2	96.3	96.4	96.3	96.3	96.2	96.2	96.3
Avg. Weekly Hours in Mfg.	40.1	40.2	40.1	40.0	40.1	40.2	40.2	40.2
Rate of Price Inflation	5.2	4.9	5.6	4.7	4.8	4.9	4.8	4.7
Relative to U.S. CPI-U**	96.7	96.7	96.8	96.7	96.7	96.7	96.7	96.7
Personal Income (mil\$)	81093	86060	91770	80185	81733	82891	84193	85387
% Change	7.4	6.1	6.6	3.2	7.9	5.8	6.4	5.8
Disposable Income (mil\$)	68736	72892	77083	67977	69243	70177	71394	72355
% Change	7.8	6.0	5.7	2.6	7.7	5.5	7.1	5.5
Real Per Cap. D.I. Index**	115.3	116.4	116.3	114.7	115.5	115.6	116.1	116.3
Relative to U.S.**	106.7	106.4	105.8	106.2	106.6	106.5	106.5	106.5
Rel. Business Cost Index**	96.6	96.5	96.6	96.6	96.6	96.5	96.5	96.5
Manufacturing**	95.7	95.6	95.7	95.7	95.7	95.6	95.6	95.6
Non-Manufacturing**	97.0	96.9	97.0	97.0	97.0	96.9	96.9	96.9

*Thousands of people.

**Indexes equal 100 in calendar 1973.

Massachusetts Business and Economic Report

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High Tech and High Performance: The Digital Experience

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Introduction

In recent years a growing number of US corporations have sought to improve productivity as the key to competitiveness in world markets. Keeping pace with the productivity gains of Japanese and Western European competitors is indeed a challenge. The American worker's outlook, steeped in independence and individuality, has traditionally held the dollar as its primary goal. However, to enhance productivity, progressive US business organizations are attempting to transform the very definition of work and many of its accompanying values. Today, an honest day's work for a fair day's pay must go hand-in-hand with personal dedication and commitment. The worker of the 1980s must feel an urgency about work, a personal drive to contribute.

The Digital Equipment Corporation has been a leader in fostering this new outlook. Digital understands that automating the manufacturing process is only one part of the answer to increased productivity. The complete answer requires the applied skill and commitment of each worker. Three years ago, Digital set out to prove this point by funding a high-performance work system in a manufacturing plant in Enfield, Connecticut.

At Enfield, the concept of "process" is not to make a piece of toast in a toaster, but to bake an entire loaf of bread from scratch. Ensuring that work tasks at Enfield reach beyond assembly was the first step in creating the culture which has contributed to Enfield's successful

high-tech performance. To date, many indicators support the Enfield approach. For example, in module building, the plant requires 40% less time, half the people, and half the space to achieve traditional output levels.

I. Work Participation Goals

The Enfield concept may be described simply as "work participation." It grew out of a desire to improve previous assembly operations. Like any other progressive company, Digital wanted to reduce errors, waste, and employee confusion over operations.

For Digital, Enfield's birth was a significant investment and an innovative departure from previous practices. According to Bruce Dillingham, Enfield's plant manager, Enfield is not just a plant, it is a culture. Indeed, Digital is an idea leader in an emerging organizational experiment in socio-technical design, partnering business purposes with human needs and organization culture. Dillingham describes that "mission" as "creation of an experiment that fosters individual growth which will maximize our ability to achieve our (five) major goals."

He describes the five goals of the "Enfield Charter" as achievement of excellence in the following endeavors:

- * Product cost
- * Quality and reliability
- * Time to market
- * Asset management
- * Quality of Worklife

Dillingham's approach views production not just as a linear, one-two-three process, but as an endeavor involving what psychologists might call a Gestalt pattern, in which process, producer, and product are in a symbiotic relationship of high dynamism and interaction. Workers must be involved, not only with the product, but with the entire process, and must view their end-products as extensions of themselves.

In this pattern, management's role is different, yet vital. Traditionally, some managers view their role as one of driving and control. But at Digital the mutual responsibilities of work sharing require each worker to recognize

and extend personal relationships with fellow team members to achieve a mutually beneficial end — productivity. The worker views the manager as a resource who sets criteria and reinforces goals. In the final analysis, the manager is both a score keeper and coach who develops plans for improving employee deficiencies rather than punishing those who fall short. Often, the entire team collaborates in these managerially directed improvement efforts. The result has been a heightened sense of cooperation and group achievement.

Dillingham has emphasized that this concept does not confuse humanizing the manufacturing process with Enfield's ultimate purpose. Work participation is not itself an end, but a means of enhancing productivity. Indeed, the ultimate object of the Enfield process is production of a superior product.

II. Means of Achieving Work Participation

How is work participation accomplished? It requires shifting the job's status as a task to that of a vital element among the worker's personal goals. In this, development of the "team" is the cornerstone. The team usually comprises 14 to 18 workers united in a common purpose, and is given team identification by a skilled manager. The team approach at Enfield is embedded in a three-layer organization structure encompassing operating, technical, and administrative groups.

At Enfield the operating team is the basic productive unit. Operating teams build the product for two businesses — large Disks and Tapes. (A third business for Low-End (small disk) products, is also planned.) At the workplace six operating teams of 14 to 18 persons each, manage their own operations by meeting daily to make decisions about production, equipment, processes, and interpersonal relationships. Technical and administrative teams provide critical information, support systems, and material, thus enabling operating teams to meet their daily production schedules. Technical teams also ensure that operating teams integrate new products, processes, and equipment, thus keeping the plant at the leading edge of Digital's technology.

Assimilation of new employees into the Enfield environment takes about three months. New hires receive self-paced assimilation packages, which hold them responsible for much of their own learning about the Enfield plant and the larger Digital corporation. New employees also attend a one-week orientation program which introduces team concepts and provides experiential learning about working within a team.

Next, the employee joins an operating team. The new member receives three months' training in the core process of module building. Eventually, the new employee is certified in the twenty-two operations required to build the product.

Finally, new hires attend "assimilation seminars," where they begin to internalize the work system and Enfield's visions. These seminars or workshops are conducted by management as well as by seasoned team members. The management team helps employees to in-

ternalize the plant's goals by relating them to individuals' specific skills. The end achievement is that everyone at Enfield understands the plant's charter, mission, purpose, and goals.

III. What Work Participation Means to Employees

We have thus far emphasized Enfield's business objectives. Hand-in-hand with these are the values that provide the very foundation for how the work gets done and how employees feel about their jobs. The following interview with Enfield employee Bob Chelli articulates many of the values that underlie his considerable job satisfaction.

Before coming to work at the Enfield plant, Bob Chelli had spent twelve years in another, more traditional, manufacturing environment.

"The biggest difference for me," notes Bob, "is that I am in more control of what I am doing now. I've got a say in what I do and in the way things should be done."

As a member of one of Enfield's operating teams, Bob has been trained in every aspect of the modules operation. He not only performs every step required to build and test the modules that Enfield produces, but also participates in production scheduling decisions, shipping and receiving activities, interviewing and hiring, and other functions.

"In my previous job, I knew nothing about the overall system. Although I also built modules there, I did not understand the overall module-building process. I worked in one area, and didn't go into any other area. I wasn't allowed. It wasn't my job.

"Here I understand everything that goes on under this roof. It's a nice feeling being involved with scheduling, customer interface, and meeting revenue goals. I feel like I'm really contributing to Digital. I understand what the product I'm building means to Digital, and I understand the total module business.

"We're involved in what product to build and when, depending on customer needs and the availability of parts. If Colorado Springs (our customer) calls up and says, 'we really need more 86s' (a product number), we can make a decision to switch gears and give them what they want.

"Before I came here, I was on a narrow path. So many options have opened up for different careers — in materials; in purchasing — areas that I never knew anything about."

At Enfield, development within teams is carefully structured. In addition to spending three months learning to build the product, team members receive training in such skills as giving and receiving feedback, facilitating meetings, making presentations, managing conflict, and team building. Each team develops performance contracts that tie its goals to those of the plant, the business, and individual career development.

Enfield's philosophy of compensation encourages and pays for the acquisition of knowledge and skills. Seven skill steps constitute the core and support work needed to run the business. As people certify across skill blocks, salaries increase. Performance is monitored

through contracting and daily feedback among team members. Enfield's skills-based pay system is the first of its kind at Digital.

Other Digital facilities are beginning to experiment with the Enfield concept, and visitors from other companies have toured the plant to study Enfield's work system. These tours are conducted by employees from all levels of the plant, who encourage visitors to question Enfield employees about their roles in the work environment.

Responses to these questions vary in focus but not in enthusiasm. Everyone at Enfield understands that he or she is here to build modules. Making it happen through work participation doesn't change the product, but does produce modules faster and cheaper. And with the entire work force — management and workers alike — enjoying the process, working can be fun.

One year after start-up, plant manager Dillingham, in a report to the rest of Digital, evaluated the Enfield plant's strengths and weaknesses. While applauding the plant's improved productivity and worker satisfaction, he also recounted lessons from the Enfield experience. He remarked that creating and sustaining major innovations required setting sights high and broad, but being prepared to flexibly adapt tactics to meet specific obstacles and challenges. He added that Enfield's three-level structure, unlike many more hierarchical organizations, rendered both strengths and weaknesses more visible and public. Indeed, Enfield's "flat" organizational structure readily exposed imperfections, ensuring that they be dealt with. Finally, he emphasized that work participation be kept in proper perspective; that is, as a means to profits and productivity rather than as an end unto itself.

The Coming Revolution in Health Care

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As a leader in economic innovation, Massachusetts has fostered many changes during the past decade. Other states like Texas and Colorado have emulated Massachusetts' successful transition to high technology. Now, Massachusetts is on the verge of another significant transition — this time in health care. In this, the Commonwealth can look to such states as California, Minnesota, Illinois, and Ohio, where the medical profession, corporations, and consumers are together restructuring the health care system.

Supply and Demand in Medicine

Between 1960 and 1980 the number of physicians in the United States grew from 251,900 to 466,600. For years, medical schools have been turning out graduates at ever-increasing rates; thus, the concept of physician glut is becoming real. A medical group in Minnesota recently hired a full-time family practitioner for under \$30,000 a year for a fifty-hour workweek. In Detroit, doctors staff hospital emergency rooms for under twenty dollars per hour.

This increasing supply of physicians has led to new health-care alternatives. First introduced in Providence, Rhode Island, free-standing emergency rooms are now commonplace in many communities. These facilities handle minor emergencies and can be established in most states with only a business license. The major competitive advantage of these centers is price — often 50% lower than standard hospital emergency rooms. Many innovative free-standing centers are competing directly with physicians' private practices. A successful free-standing emergency room in Fort Collins, Colorado advertises that patients are not charged for any follow-up visits to the center.

Physician supply has led to other changes — such as house calls! Once the calling card of the family physician, house calls disappeared during the 1960's and 70's. Now, tougher times for physicians are leading to their re-appearance as a competitive advantage to a physician's practice. One service in New York City advertises that a doctor will be at your door within 35 minutes of your call.

Problems of supply and demand not only affect physicians. Hospitals have also faced problems of oversupply. During the 1950's and 1960's, many hospitals in the United States followed aggressive building plans. The bed-size capacity of the health care system grew dramatically, the results of which are apparent today in most communities.

In recent years, technological advances in medicine have influenced the hospital's important source of revenue, the patient's length of stay. Orthopedics, plastic surgery, and ophthalmology are a few of the medical specialties in which a patient's treatment formerly entailed at least a few days in the hospital. Technology has changed these revenue sources. Many surgical procedures can now be accomplished in one day — in by 7 a.m. and out by 5 p.m. The results are clear — empty beds and excess capacity because of reduced length of stay.

Coupled with technological changes is a major change in the payment system. Instituted in some states and now becoming the norm is a payment mechanism referred to as DRG, diagnostic related groups. Hospitals are now in the retail business. For years, hospitals charged patients when they left the facility. Not knowing the price, the customer entered the store (hospital), bought the product (treatment), and was finally told the amount due when leaving. What a great way to run a business, the margin is guaranteed! DRGs have changed the business strategy, which has now moved from a

cost-plus to a market-price system. Insurance companies will pay by diagnosis. Length-of-stay is not the issue. The efficient hospital wins, the inefficient hospital loses.

The problem of oversupply is real. It's been predicted that one-third of the present supply of hospital beds will disappear by the end of the decade. The fight is now one for survival. Hospitals are aggressively pursuing new service lines to guarantee business and to find revenue. To maintain loyal physicians (who hopefully will admit profitable patients under DRG), many hospitals have entered into joint venturing arrangements with their medical staffs. Other hospitals have sponsored Preferred Provider Organization (PPO) plans for corporations. Selected physicians are enrolled who charge discount fees to company employee subscribers of the plan. The selected physician, of course, admits employees to the participating hospital.

A Changing Consumer

Consumers are also playing a dramatic role in the restructuring of health care. A New York Times poll in the Spring of 1982 revealed some significant changes in consumer preferences. Fifty-eight percent of the consumers surveyed said they would be willing to have their routine illness treated by a nurse or doctor's assistant rather than by a doctor if it would reduce cost. And half said that they would go to a clinic to see an available doctor rather than their own if it would reduce cost.² As physician prices rise, the days of physician loyalty may be waning.

Consumer concern with cost may account for some of the dramatic growth of Health Maintenance Organizations (HMOs). Once strictly a phenomenon of the West Coast, HMOs are now found nationwide. Honolulu has over 20% of its population enrolled in HMOs, Minneapolis over 30%, Denver over 25%, and Miami 20%. These plans allow consumers to budget an exact amount for health care. While some health care providers question the care provided within these systems, consumer acceptance argues against such typecasting. Even the Armed Forces have embraced HMOs. Under a new insurance plan, military personnel can now go off base for medical care. Presented with the option, many are doing just that.

Consumers are changing the health care system more subtly because of their own expectations. At no time in the history of the United States has the population been so well-educated. Education does several things for consumers, including raising their expectations. Better educated consumers expect more from medical providers. A recent survey in *Medical Economics* reported that 59% of the consumers who switched doctors did so because the doctor was cold or abrupt. Consumers expect to be treated as people, not just as cases.

Consumers are expecting more and know more. In most book stores today, an entire section is devoted to self-diagnosis and treatment books. One of the leading selling trade books is the *Physician's Desk Reference Guide*. Even the American Medical Association has got-

ten into the act. The AMA publishes a self-help guide with over 200 flow charts to help consumers diagnose their own illnesses.

Private Industry Involvement

No societal institution is likely to surpass private industry in changing health care. For years, health care coverage has been considered a basic right of every employee. To tamper with health care benefits would surely debase a union's worth and incur consumer dissatisfaction. The cost of health care has changed this view. Health care is increasingly viewed, not as a part of overhead, but as a controllable cost. Companies are realizing that every dollar saved on health care goes directly to the bottom line. For the past few years, many executives have searched for the secret to Japanese success — Theory Z, Quality circles, and government support are but a few of the explanations. They should consider health care as a reason. The average health care bill per employee for Chrysler is \$5,700; for Mitsubishi in Japan it is only \$815.

Companies are now trying several approaches to control a yearly 12% rise in health benefits. Strong support for alternative delivery systems may be one answer. Over 70% of General Mills' employees in Minneapolis are enrolled in HMOs. R. J. Reynolds, Scott Paper, and Uniroyal all have developed their own HMOs for their employees.

A second means of controlling company costs is to challenge those costs directly. Carson Pirie Scott of Chicago allows employees to keep 50% of any overcharge discovered in a medical bill. Lockheed Corporation in California challenges 70% to 80% of all medical bills submitted to the company. Adjustments have been won on up to fifty percent of the bills. Some of Chrysler's programs with projected savings of millions of dollars include the following:

- a foot surgery screening program to eliminate needless surgery (savings: \$1 million/yr.)
- a program to promote the substitution of generic drugs (savings: \$250,000/yr.)
- a second option for non-emergency surgery (savings: \$1 million/year)
- a program to promote outpatient surgery (savings: 2 million/year)

Alternative programs like these may be the least aggressive form of change imposed upon the health care system. In contrast, the most dramatic may be the growing number of health care coalitions forming in many communities. Membership in these coalitions is usually restricted to industries in the community. These coalitions have lobbied, commented upon, and argued for new programs, changes, and cutbacks by health care providers in their communities. In Fort Collins, Colorado, for example, the local coalition of IBM and Hewlett-Packard lobbied at the state capital against the community hospital's expansion plans. Their concern was cost, regardless of the proposed case made by the hospital for need.

Final Comments

The Northeastern United States has been viewed as having a strong, high-quality health care system. Yet, quality is also evident in other parts of the country. In fact, changes among providers, consumers, and corporations that have affected the delivery and cost of health care have been more pronounced outside the Northeast. The next few years in Massachusetts may see similar upheavals and hopefully benefits, as health care becomes increasingly competitive.

Footnotes

1. Robert Teitelman, "Taking the Cure," *Forbes* (June 4, 1984), 82-91.
2. *New York Times* (March 29, 1982).
3. *Medical Economics* (May 30, 1983).

The Massachusetts Economic Policy Analysis Model Track Record: 1977 — 1983

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The Massachusetts Economic Policy Analysis (MEPA) model has been used to make forecasts of the state economy extending out for three years quarterly for the last seven years. Since mid-1978 these forecasts have been published quarterly in the Massachusetts Business and Economic Report. Table 1 shows the mean absolute percentage error for the forecasts made in January in each of those years.

The MEPA mean absolute percentage errors for the major concepts predicted by the model are shown in the first column of Table 1. The errors for the comparable variables in the U.S. forecasts by Data Resources, Inc. (DRI) on which the MEPA Massachusetts forecasts were based are shown in the second column. The MEPA forecasts were made at a much more detailed level and then aggregated. The DRI inputs actually used were also on a much more detailed level than these aggregate variables. For each MEPA forecast, 94 U.S. variables were used including employment forecasts for each of 28 U.S. industries. However, the forecast errors are given for MEPA and DRI aggregate forecast variables to provide a summary basis for evaluating the size of the error. Surprisingly, the error in the state forecasts was usually *smaller* than the error in the U.S. forecasts used as inputs. This result is difficult to explain because the state forecast was made conditional on the U.S. forecast.

In Table 2, the first three variables are employment variables. Here we note that the MEPA average absolute error (Table 1) in predicting employment in manufacturing was two percent in the first year and about five percent in the second and third years while the error in predicting non-manufacturing was slightly more than half this amount. Despite the relatively good performance of the Massachusetts economy relative to the U.S. when compared with the period preceding 1977, we still note by looking at the percent error (Table 2) an upward bias in the MEPA forecasts after the first year of forecast.

Our hypothesis is that this bias as well as a substantial proportion of the error in the MEPA forecast was due to the forecast's conditionality on a U.S. forecast that itself was in error. To test this definitively, we could reproduce each of the MEPA forecasts from 1977-1983 with all inputs to the model the same except for the U.S. forecast. Instead, we examined the errors in each of the individual MEPA and DRI forecasts. We found that the correlation between the employment forecast errors was .91. This high correlation indicates that a high proportion of the MEPA error is probably due to the error in the DRI forecast.

The consumer price index forecast is a prediction of the Boston area All-Urban Consumer Price Index. This forecast is closely related to the DRI forecast of the U.S. Consumer Price Index. Therefore, it is not surprising to find very close forecast records. An examination of the individual forecasts shows underpredictions of inflation in the earlier forecasts and overpredictions in the later forecasts.

The MEPA forecasts of personal income and personal disposable income are outcomes of a full simultaneous solution of the MEPA model. Thus, they are not directly related to the DRI income forecasts. Here, we find MEPA errors of about one percent in the first year, three percent in the second year and four percent in the third year. Table 2 shows a slight tendency by both MEPA and by DRI to overpredict the level of personal income. The correlation between the errors in the MEPA and DRI personal income forecasts was .92. Comparing MEPA and DRI forecasts, we find that the DRI forecast error is again slightly higher. This is hard to explain since one would expect that errors made in the national forecast would be incorporated into the state forecast and that, then, additional error would arise from errors introduced by the MEPA model. Our only explanation, is that judgmental fine tuning adjustments of the MEPA forecast may have offset, in part, errors in the national forecast inputs used by the model.

In summary, there is evidence that any error that might have been inherent in the MEPA model was more than offset by fine tuning of the MEPA forecast in the presence of errors in the U.S. forecast. This forecast record provides important indirect evidence validating the structural relationships incorporated into the MEPA model and in other current state models that incorporate the same modeling approach.

Table 1

Mean Absolute Percentage Error for
Ex Ante Forecasts 1977-1983

	MEPA Massachusetts Forecasts	DRI U.S. Forecasts
Total Employment		
One Year Ahead	1.4	1.1
Two Years Ahead	3.2	2.3
Three Years Ahead	3.4	3.1
Manufacturing Employment		
One Year Ahead	2.2	2.9
Two Years Ahead	4.9	6.1
Three Years Ahead	5.0	5.3
Non-Manufacturing Employment		
One Year Ahead	1.4	0.8
Two Years Ahead	2.6	1.8
Three Years Ahead	3.1	2.6
Consumer Price Index		
One Year Ahead	1.3	2.0
Two Years Ahead	4.6	5.4
Three Years Ahead	8.2	9.6
Personal Income		
One Year Ahead	1.1	1.4
Two Years Ahead	3.2	3.9
Three Years Ahead	4.1	6.1
Disposable Income		
One Year Ahead	1.2	1.2
Two Years Ahead	2.8	3.7
Three Years Ahead	3.7	5.6

Table 2

Mean Percent Error for
Ex Ante Forecasts 1977-1983

	MEPA Massachusetts Forecasts	DRI U.S. Forecasts
Total Employment		
One Year Ahead	-0.6	-0.5
Two Years Ahead	0.4	0.4
Three Years Ahead	1.6	1.6
Manufacturing Employment		
One Year Ahead	-0.8	-1.3
Two Years Ahead	2.4	0.9
Three Years Ahead	4.7	1.9
Non-Manufacturing Employment		
One Year Ahead	-0.5	-0.5
Two Years Ahead	-0.2	-0.3
Three Years Ahead	0.7	0.5
Consumer Price Index		
One Year Ahead	0.1	-0.7
Two Years Ahead	-0.3	-1.5
Three Years Ahead	-2.2	-4.4
Personal Income		
One Year Ahead	-0.1	-0.3
Two Years Ahead	0.6	0.7
Three Years Ahead	1.3	1.0
Disposable Income		
One Year Ahead	0.4	0.1
Two Years Ahead	1.6	1.4
Three Years Ahead	2.2	1.5

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The Bay State Skills Corporation: An Economic Development Tool

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Theories about economic development come and go, as governments try to determine how they can best serve the needs of the business community. Twenty years ago it was presumed that, to grow and prosper, businesses needed venture capital, industrial revenue bonds, and government assistance in obtaining rights to land use development. Accordingly, state governments devised economic incentives to meet those needs — incentives that have been well received by the business community and continue to be widely used.

But in Massachusetts, a different need began to appear about ten years ago. Massachusetts companies started to talk about the need for trained personnel, and began to get worried that, as they looked down the road, a shortage of trained labor would significantly hurt their ability to grow and expand in this state.

Training programs are not a new phenomenon in Massachusetts; they have been running for 20 years or so. But until recently, training programs were funded entirely by the federal government and were geared more to meeting the needs of the economically disadvantaged worker than to meeting the skill shortage projections of business and industry.

So several years ago, a new experiment was begun in Massachusetts. For the first time, the state legislature put some money aside for skills training. But the legislature wanted this new program to operate differently from those in the past — it should be a business-education partnership, where business would define skills needs and participate in the actual training effort, and government would supply the dollar funding. Under this model, both the state's funding and the business community's

expertise would go directly to educational institutions, where the training would take place. This partnership was a novel idea at the time. It presumed that all three parties — government, business, and education — could work together, that they each had a vested interest in one another's success. But would the partnership work? The Bay State Skills Corporation became the laboratory that looked to answer this question.

BSSC Model — A Partnership

The idea behind the Bay State Skills Corporation is simple: A business looks at its personnel needs and discovers that it is facing a skills shortage. The shortage can be in entry-level jobs such as data entry clerks and secretaries, or it can be in more advanced jobs such as quality control supervisors or electrical engineers. BSSC presumes that each business that identifies a skill shortage does not want to be in the training business itself; instead, it wants academic institutions around the state to administer its education or training.

A business then sits down and talks to an educational institution, be it a community college or university, and *together* the two organizations decide what kind of training should take place. Under the BSSC model, the educational institution holds the actual classes and does the instructing, but the business partner plays a vital role to ensure that instruction meets that company's needs. Businesses loan technical instructors; help develop the course curriculum; help recruit and screen the trainees; donate appropriate training equipment; provide internships at their facilities — in short, business puts its imprint onto all aspects of training to ensure that whoever completes a training program acquires the skills that the employer is really looking for.

And what does BSSC do? It provides the educational institution with a cash grant that pays for the teachers' and the administrators' time in setting up and running the program — a match that equals the dollar value of the firm's participation.

Examples of Partnership Programs

The Bay State Skills Corporation has used this approach successfully for the past three and one-half years. Over

400 companies have linked up with 100 different educational institutions to train approximately 4,500 people; 86% of the graduates of these programs have been placed in jobs in their training-related field. Some actual examples appear below.

About 30 small machine shops north of Boston were constantly short of entry-level machine operators. They banded together and set up the Boston Tooling and Machining Association. They outfitted the Association's training program with their equipment, loaned some of their own personnel to do the actual instruction, and now hire graduates of the program to come work for them.

At Bentley College, a series of discussions with Apollo Computer, Lotus Development, Digital Equipment Corporation, Prime Computer, Data General and others revealed that these companies had a real need for technical writers of systems software. The companies formed an advisory committee to design the curriculum and recruit and screen trainees. The companies also provided internships for each trainee. The program has successfully placed 100% of its graduates; these companies are now turning to Bentley College without BSSC assistance, and are using the College as a recruitment source.

In Springfield, five companies banded together to see if they could find a labor force skilled in CAD/CAM applications to mechanical drafting. The Massachusetts Career Development Institute is training 22 people, some who are currently employed and others who are looking to join the labor force. The companies are helping in recruitment, selection, curriculum development, and internships.

Successful partnerships have entailed varied arrangements: With direct company participation, Tufts University is launching a masters' degree program in electro-optics; Northeastern University has conducted a very successful program to train women to be managers of information systems; and a community-based organization in Lawrence, Mass. is working with several private ambulance companies to train emergency medical technicians.

Economic Development

Business-education partnerships can be particularly effective in encouraging company expansions and relocations. The availability of a skilled labor force is often the lynch pin in a company's decision to open a new facility.

Due to an aggressive outreach effort by the Fall River Office of Economic Development, a new high-tech company is beginning production of computerized test equipment for integrated circuits and microprocessors in Fall River. LTX Corporation, a fast-growing supplier of test equipment to the semi-conductor industry, has linked up with BSSC and Bristol Community College to train 100 people for employment at the company. LTX is developing a customized curriculum for both entry-level training and the upgrading of components. The company has been impressed with the work ethic of the prospective applicants and believes that they can be "trained to do just about anything."

The GCA Corporation, a major supplier of factory automation and semi-conductor manufacturing equipment, is conducting on-going training in conjunction with BSSC and the city of Lawrence to train 400 Lawrence area resi-

dents at GCA's new production facility in the Pacific Print Works Complex of Lawrence. Initial training covers electronic sub-assembly and machine-shop work emphasizing state-of-the-art computerized equipment. The curriculum is being devised with assistance from Wentworth Institute of Technology and Northern Essex Community College. This multi-partner approach is often employed in BSSC programs.

Special Institutes

BSSC has learned from experience that a constraint in producing a skilled workforce is the degree of expertise at educational institutions in the Commonwealth. Unfortunately, faculty members often fail to keep up with developments in the industrial workplace. Through no fault of their own, faculty members, possessing outdated information about a technology, must teach students about a related field of study.

To help address this need, BSSC has designed another new model, Special Institutes for Industry-Faculty Development. Special Institutes bring industry experts to universities to share with engineering and science faculty state-of-the-art developments in particular technologies. College faculty members spend two to three weeks during the summer in an intensive program devoted to a new and emerging technology. Companies send their experts to do the instructing, which teachers and entrepreneurs together absorb. BSSC expects that these Special Institutes will enable faculty members to take their newly acquired knowledge back to their students in the classroom.

Centers of Excellence

The model of BSSC's business-education partnerships holds considerable promise as a tool to support Governor Dukakis and Secretary Murphy in their Centers of Excellence program. Through this program, the state is encouraging business-education exchanges and development in five emerging technologies: microelectronics, biotechnology, polymer science, photovoltaics and marine science. The Bay State Skills Corporation has already started to use its partnership model to bring faculty and business together to share their knowledge. This is a small but important part of the Centers of Excellence initiative.

The question can now be answered: business and education partnerships *do work* in helping prepare a skilled labor force. Perhaps the evidence from other countries should have prompted Massachusetts, and indeed the country as a whole, to try this experiment earlier. The Japanese have long been recognized for their success in harnessing higher education to meet the needs of their emerging technologies. And business-education cooperation is likewise evident in many other growing economies around the world.

The Bay State Skills Corporation is a small beginning, but at least we have begun. As William Daggett, Vice President for Manufacturing at the Gillette Company, says: "The concept of BSSC and the idea of uniting industry and education in educating today's workforce is an idea whose time has come. It may be that the U.S. lags behind such successful countries as Germany and Japan because we have been hesitant to start such an idea." But we have come into our own, and the future of these partnerships looks bright.

Some Observations on Bhopal and Other High-tech Tragedies

Louis Wigdor

Editor

Massachusetts Business & Economic Report

In the wake of the Bhopal tragedy, business leaders have engaged in unprecedented soul searching. At this writing, responsibility for the disaster appears to reside in some proportion among all the principal parties to the affair: Union Carbide, its Indian subsidiary, and India's national, provincial, and local governments. While charges and countercharges abound, analysis of Bhopal and other recent industrial disasters has led to the growing consensus that accidents involving complex industrial technologies are bound to remain with us. Indeed, risk experts contend that over the past two decades the world has experienced industrial disasters of the technological magnitude of Bhopal about once every two years.¹ The difference between Bhopal and most of the others is the former's staggering number of casualties, most of whom lived in shanties around the perimeter of the Union Carbide plant. Bhopal, then, is the most recent tragedy in an ignominious lineage that includes such disasters as the following:²

Date	Place	Event	Consequences
11/19/84	Mexico City	Vapor-cloud explosions at liquified natural gas farm	452 dead 4200 injured
4/3/80	Somerville, MA	Railroad tank car spill releases lung-searing chemical	70 injured 30,000 evacuated
2/26/78	Youngstown, FLA	Railroad tank car spill releases liquid chlorine which combines with air to produce lung-damaging gas	8 dead 70 hospitalized
7/10/76	Seveso, Italy	Chemical plant dioxin leak	2000 injured
6/1/74	Flixborough, England	Chemical plant pipe rupture creates explosion	28 dead 100 injured

Why should we expect that high-tech industrial accidents will continue to occur? "The real problem," writes Anthony J. Parisi in *Business Week*, "is not so much that technological man pays too little mind to the hazardous things he understands, but rather that he undertakes too many hazardous things."³ "Too many" includes more than 12,000 chemical plants worldwide, scores of nuclear power plants, equipment for handling liquified natural gas and other explosive fuels, laboratories for studying new biological organisms, and — perhaps most critical of all — risks associated with the transportation of hazardous substances. Because these endeavors entail an enormous number of activities, "the aggregate probability of something catastrophic happening," notes mathematician and risk analyst Kristin Shrader-Frechette, "is much higher than people realize."⁴

Coupled with the growth of potentially hazardous high-

technology activities are risks inherent in the structures of the technologies themselves. Nuclear power plants and many chemical refineries are vulnerable to weaknesses that accompany two structural characteristics: tight coupling and systemic complexity.* When a valve, pipe, or circuit malfunctions due to normal wear and tear, a system's tight coupling and complexity can amplify and complicate the problem in unanticipated ways.

When a system's components are tightly coupled, their interactions are often rapid, rigid, and irreversible. Because there is little slack or buffering between components, it is often impossible to delay or prolong a reaction. For example, when certain chemicals are inadvertently combined, (as in accidental tank and pipe discharges), they can react with uncontrollable swiftness and intensity. Accordingly, designers attempt to anticipate a system's potential weaknesses and design appropriate buffers and redundancies into the system. But pipes, gauges, valves, and the human beings who operate them can fail in unanticipated ways.

A second structural source of accidents in nuclear and chemical plants derives from their systemic complexity. Indeed, as systems grow in size and the number of diverse functions that they serve, they exhibit such complex characteristics as branching paths, feedback loops, and jumps between linear sequences. Complex systems are especially prone to unplanned, unexpected sequences, many which are neither readily visible nor immediately comprehensible. For example, unexpected complications and possible accidents can arise from the following characteristics:

Proximity of independent components —

The closer that tanks, pipes, etc. are to one another, the more readily can their contents interact to compound a leak or emission.

Common-mode connections between components —

When a component serves multiple independent functions, it is said to embody a common mode. Thus, failure in a heater that both heats gas in a tank and absorbs excess heat from a chemical reactor will upset both subsystems.

Unfamiliar or unintended feedback loops —

Example: Consider the predicament involving two tanks linked by pipes restricted to a one-way flow of a gas or liquid. Unexpected temperature or pressure changes in tank #2 can force a reverse flow through the pipes. If critical valves fail to check these reverse flows, explosions can ensue from seepage into, and subsequent chemical reactions inside, tank #1.

Balance between automated and unautomated controls —

Monitoring a complex system's many interacting components requires many detection devices and controls. For example, the control panel of a nuclear plant is considerably denser and larger than that of an oil or coal plant. Fortunately, nuclear plant designers can reduce operator errors that derive from the sheer number and complexity of these controls. This they accomplish by automating subsidiary interactions, thus, leaving only main control parameters to the operators. Some systems, in fact, require extensive automation of controls because otherwise there is insufficient time for operators to react to certain system errors. But while automated controls may simplify and hasten the operator's task, they reduce the operator's expo-

*My arguments concerning these characteristics are adapted from Charles Perrow, *Normal Accidents*, 1984, BASIC Books. pp. 72-96.

sure to and control over the system's components. Thus, complex technological systems all possess some carefully considered ratio of automated controls to those that are left to the operator's discretion. Unfortunately, these imperfect tradeoffs must often be reconsidered after costly trial-and-error accidents.

To summarize: A tightly coupled or complex system can complicate the simple malfunctions that arise within it. Valves, pipes, and circuits can eventually fail in any system due to normal wear and tear and to extreme changes in temperature and pressure. But in complex or tightly coupled systems, these events can trigger unexpected complications and malfunctions.

Given these risks it is important that firms and their regulators strive for greater safety. The uproar that followed Bhopal, for example, generated numerous constructive prescriptions. For example, appropriate zoning and plant siting can better protect surrounding communities from potentially hazardous emissions. The settlement of shantytowns along the perimeter of the Carbide plant, many have argued, was indefensible. Others have recommended that corporate headquarters regularly audit the safety of their Third World plants and provide them with sophisticated backup safety systems to compensate for inadequacies in local training and staff. Some reductions in economies of scale (e.g., increased process plant throughput and storage tank volumes) can also contribute to plant safety. For example, pressurized liquefied gas storage vessels can reach two thousand tons; in an accident it is certainly conceivable that a significant and, perhaps, disastrous quantity of a tank's contents could be released instantaneously.⁵

These and other prescriptions, of course, have lately been in great supply. But effective reduction of hazardous risk in Third World settings behooves multinational corporations and their foreign host countries to rethink some of their mutual arrangements. In the case of Bhopal, for example, Union Carbide must certainly bear most of the blame, but the Indian national and provincial governments are themselves responsible for a relatively unregulated safety environment. (Ironically, the Indian government's massive suit against Carbide has obscured the former's complicity in creating the unregulated climate that contributed to the disaster.)

Indeed, poor developing nations fiercely compete with

each other by offering multinational corporations the most attractive combination of cheap and plentiful labor, tax incentives, and unregulated business conditions. Many Third World governments remind us that extensive regulation is a luxury that only industrialized nations can afford. Moreover, developing nations contend that the United States and Western European nations themselves industrialized with a minimum of regulatory interference. Developing nations also point out the undeniable benefits that foreign investment brings to their economies and standards of living.

Certainly though, tragedies like Bhopal *must* be avoided. Unfortunately, in recent years Western manufacturers have increasingly transferred hazardous production processes from their own highly regulated parent nations to Third World countries. Examples include the benzedine dye industry in India, asbestos textile production in Latin America, and vinyl chloride and arsenic production facilities in South Korea and the Philippines.⁶

Because the risk of grave industrial accidents appears to be increasing, multinational firms and their developing host nations would do well to work out strong safety regulations and policies. At the same time, the multinationals would maintain their customary competitive advantages of inexpensive and accessible raw materials, cheap and plentiful labor, tax incentives, and convenient markets. But even with increased risks, the individual firm may rationally ask whether *its* relatively unlikely chance of becoming another Union Carbide is worth the economic costs in regulatory baggage. Governments may likewise question whether regulations are economically and politically rational, if firms like Carbide can be shouldered with most of the political and economic responsibility and blame. But hopefully, like the survivors of Bhopal, business and political leaders will consider arguments that transcend the limited concerns of political and economic rationality.

Notes

¹*Boston Globe*, December 17, 1984, p. 53

²*ibid.*, p. 54.

³*Business Week*, December 24, 1984, p. 61.

⁴*ibid.*

⁵R.A. Cox and H. Slater in R.A. Waller and V.T. Covello, eds., *Low Probability High Consequence Risk Analysis*, 1984, New York, Plenum Publishing Corp., p. 257.

⁶Editorial in *Nature*, Vol. 273, June 8, 1978, p. 415.

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